"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering (Power System)"

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DESIGN SWITCH MODE POWER SUPPLY (SMPS) USING PULSE WIDTH MODULATION (PWM) CONTROLLER TECHNIQUE

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This thesis is submitted as partial fulfillment of the requirement for the award of the Bachelor Degree of Electrical Engineering (Power System)

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Author : MOHD SHAHRUDDIN BIN HARUN

Date : ________________

Specially dedicated to

My beloved parent

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ABSTRACT

Today, two types of DC power supply can be found in the market, Switch-Mode Power Supply (SMPS) and linear power supply. However, many customers prefer to choose SMPS than linear power supply because for same power rating, SMPS is smaller, cheaper and lighter than linear power supply especially transformer. The high frequency switching transformer that is used in SMPS is smaller and lighter than the transformer that is used in linear power supply. SMPS also have better efficiency than linear power supply. This project is focusing on developing SMPS using flyback converter topology. This flyback converter topology is chosen because it affords to carry power till 150 watts and few components are used to construct the circuit. There is high frequency switching transformer at the middle of flyback circuit that is used to isolate and step-down the high DC voltage and low DC voltage. Only one switching element is used in this flyback topology, normally MOSFET is used as switch. The on and off of the switch is controlled by PWM that generated by PIC microcontroller 16F877A. The on and off of the switch is important because the duty cycles of the PWM is used to regulate the DC output voltage. So the desire output voltage can be produced by generate various duty cycle.

(Keywords: Flyback topology, pulse-width modulation, PIC 16F877A)

ABSTRAK

Sehingga hari ini, terdapat dua jenis bekalan kuasa DC yang boleh dijumpai di pasaran iaitu SMPS dan “linear power supply”. Walau bagaimanapun, ramai pelanggan lebih memilih SMPS daripada ‘linear power supply” kerana untuk kadar kuasa tenaga yang sama untuk kedua – dua bekalan kuasa DC, SMPS lebih kecil, murah dan ringan berbading dengan “linear power supply” terutamanya transformer. Transformer berfrekuensi tinggi yang digunakan dalam SMPS adalah lebih kecil dan ringan berbanding dengan transformer yang digunakan dalam “linear power supply”. Projek ini lebih mengfokuskan kepada membangunkan SMPS menggunakan topologi flyback. Topologi flyback ini dipilih kerana ia mampu membawa tenaga sehingga 150Watts dan hanya sedikit komponen diperlukan untuk membangunkan litar flyback ini berbanding dengan topologi lain. Terdapat transformer frekuensi tinggi berada ditengah-tengah litar flyback dimana ia digunakan untuk menurunkan dan mengasingkan voltan DC tinggi dengan voltan DC rendah. Hanya satu unsur suiz digunakan dalam topologi flyback ini biasanya mosfet digunakan untuk bertindak sebagai unsur suiz. PIC microcontroller 16F877A akan digunakan untuk menghasilkan PWM yang akan mengawal buka dan tutup suiz dimana denyutan ini penting kerana denyutan ini berhubungkait dengan penghasilan keluaran voltan DC. Jadi, keluran voltan DC yang dikehendaki boleh diperolehi dengan mengawal denyutan ini.

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LIST OF ABBREVIATIONS

PWM	-	Pulse-Width Modulation
SMPS	-	Switch Mode Power Supply
DC	-	Direct Current
AC	-	Alternate Current
MOSFET	-	Metal Oxide Silicon Field Effect Transistor
I/O	-	Input / Output
DCM	-	Discontinuous Current Mode
CCM	-	Continuous Current Mode
PCB	-	Printed Circuit Board
MGT	-	MOS Gate Transistor

LIST OF APPENDIX

CHAPTER I

INTRODUCTION

1.1 Background

This chapter explains briefly about Switch-Mode Power Supply (SMPS) and its operation. This chapter also will explain the overview of project, objectives and scopes.

1.2 Overview of SMPS Project

All electronic circuits need a supply of power. For low power consumption units, it suffices use battery or solar cell. However, for most electric appliances the power consumption is such that, an electronic power supply must be used and for high power application, surely it will use power supply because the battery even solar cell cannot provide energy for long duration usage. Two types of electric energy waveforms are used to run the electric appliances; alternating current (AC) and direct current (DC). To supply electric energy to them, there are four types of power supply are used that are AC to AC conversion, AC to DC conversion, DC to DC conversion and lastly DC to AC conversion of power supply.

In this project, the design of adjustable SMPS is used to supply electrical energy to DC appliances from $240V_{rms}$, 50Hz by using AC to DC conversion circuit. There are two common types of AC to DC power supply in market that are linear power supply and SMPS. In theory and research that made by power supply designer, SMPS is better compare to linear power supply in term of efficiency, size and weight [1] because the SMPS will regulate the voltage using Pulse-Width Modulation (PWM) technique and the transistor that is used as switch in this power supply are always fully on and fully off [1]. Thus, and "ideal" SMPS will be 100% ideal and the only heat generated is because ideal components do not exist. For linear power supply, it regulates the voltage or current by wasting excess voltage or current as heat which is very inefficient.

In this project, the designed and development of SMPS can be used to supply electric energy for low voltage and high current appliances. The development of SMPS also can be used to supply electric energy to various DC appliances such as computer, handset charger, stepper motor and many more because the output voltage for this SMPS project can be switched for 5V, 9V and 12V and it can supply power to 100 Watts of applications and below.

The switching element in this SMPS will be connected to PIC microcontroller because this microcontroller can be programmed to generate PWM. This PIC microcontroller can produce various duty cycles follows to how it be programmed. In SMPS, various output voltage will be regulated by changing the duty cycles of switching element [1].

1.3 **Objective**

The objective of this project is to:

i. Develop SMPS that regulate voltage using switching element driven by PWM technique using PIC microcontroller type.
   - Transistor will be used as switching element in this SMPS. PWM technique is applied to switch the transistor fully on and fully off.
   - PIC microcontroller is one of the PWM controllers where the PIC microcontroller can be programmed to generate various duty cycles.

ii. Develop SMPS that can produce adjustable DC output voltage using flyback converter topology.
   - This SMPS can produce adjustable DC voltage by controlling the duty cycle of PWM that connected to the transistor in flyback converter topology. The DC output voltage change when the duty cycle also changes.

1.4 **Scope of Project**

i. This project focuses on DC-DC converter.
   - DC-DC converter that will be used here is flyback converter topology. This topology is isolated converter and has one switching element only. The power MOSFET will be used as switch in this flyback converter topology because it can sustain high current and high voltage. PIC microcontroller will be used and connected to power MOSFET where the PWM generation by PIC microcontroller will give signal to power MOSFET so that it can switch fully on and fully off to get desire DC output voltage.

ii. PWM is generated using PIC 16F877A.

- PIC 16F877A is one of the microcontroller. It can be used to generate PWM. Using crystal 20 MHz, the maximum PWM frequency for this PIC type can be generated at 208.3 KHz. From programming, the duty cycle can be set start from 0 to 0.99.

iii. This project is to develop an adjustable output DC voltage for 5V, 9V and 12V only.

- This SMPS will use PIC microcontroller to generate PWM where it will control the duty cycle of switching. Using this PIC microcontroller, the duty cycle can be adjusted so that the SMPS that I will develop can produce 5V, 9V and 12V DC output voltage follow to flyback converter topology formula;

$$V_o = V_s \frac{D}{1-D}\frac{N_2}{N_1} \tag{1}$$

Where:

V_o = Output Voltage

D = Duty Ratio of Transistor

V_i = Input Voltage

$N = \frac{N2}{N1}$ = Transformer Turns Ratio

CHAPTER II

THEORY AND LITERATURE REVIEW

2.1 Switch-Mode Power Supply (SMPS)

SMPS is an electronic power supply unit that incorporates a switching regulator that is an internal control circuit that switches power transistor such as MOSFET rapidly on and off in order to stabilize the output voltage or current. Switching regulators are used as replacements for the linear regulators when higher efficiency, smaller size and lighter weight are required [3]. The efficiency of SMPS typically 80-90% as opposed to 30-40% for linear units [3]. This greatly reduces the cooling requirements and allows a much higher power density. Table 2.1 shows the comparison between SMPS and linear power supply.

Table 2.1: Comparison between SMPS and Linear Power Supply

	SMPS	Linear Power Supply
Size and Weight	- Use high frequency switching transformer (normally runs at frequency >20kHz) where it is smaller than transformer that is used in linear PSU.	- Use transformer operating at the mains frequency of 50/60Hz
Acoustic Noise	- Malfunctioning SMPS may generate high-pitched sounds. Normally the transistor switching is set above 20kHz.	

Efficiency	- Draw current at fully voltage based on a variable duty cycle and can increase or decrease their power consumption to regulate the load as required. - Regulate using PWM or at power rating below 30W, on/off control. In all SMPS topologies, the transistors are always fully on and fully off. Thus, an ideal SMPS will be 100% efficient. The only heat generated is because ideal components do not exist.	- Regulate their output using a higher voltage in the initial stages. Then expending some of it as heat to improve the power quality. - Regulate the voltage or current by wasting excess voltage or current as heat.
Radio Frequency Interference	- The current are switched at high frequency that can generate undesirable electromagnetic interference. EMI filter and RF shielding are needed to reduce the disruption interference.	- Generally do not produce interference.
Electronic Noise at the Output Terminal	- Do not exhibit ripple at the power-line frequency but do have generally noisier output than linear PSU. The noise may be related with the SMPS switching frequency or it may also be more broad-band.	- Have ripple at output and can be suppressed with large filter capacitors or better voltage regulators. This small AC voltage can cause problem in some circuit.
Power Factor	- The current drawn by simple SMPS is non-sinusoidal and do not follow supply's voltage waveform. So the early SMPS design have mediocre power factor at about 0.6 and presented a growing problem for power distribution. Power factor correction (PFC) circuit can reduce this problem.	- Do not have unity power factor but are not as problematic as SMPS.

2.2 **Flyback Topology**

2.2.1 **Operation of Flyback Topology**

Flyback topology is one of many topologies that were used in SMPS development. Normally, the maximum power capability it can handle is about 150 watts [3]. The Figure 2.1 shows the basic of flyback topology circuit. About its operation, firstly when power switch, Q1 at Figure 2.1 is 'on' with the application of 'on' pulse from the control circuit (not shown in the Figure 2.1), the current flows through the primary windings and energy stores within the core. Note that no current can flow through the secondary because of opposite dot polarity (and hence blocked diode, D). When power switch driving pulse from the control circuit is removed (during 'off' time), the polarity reverses and the current flows in the secondary winding. The current flows in either the primary or secondary winding but never in both winding simultaneously. Thus the so-called flyback transformer is not a transformer but a coupled inductor.

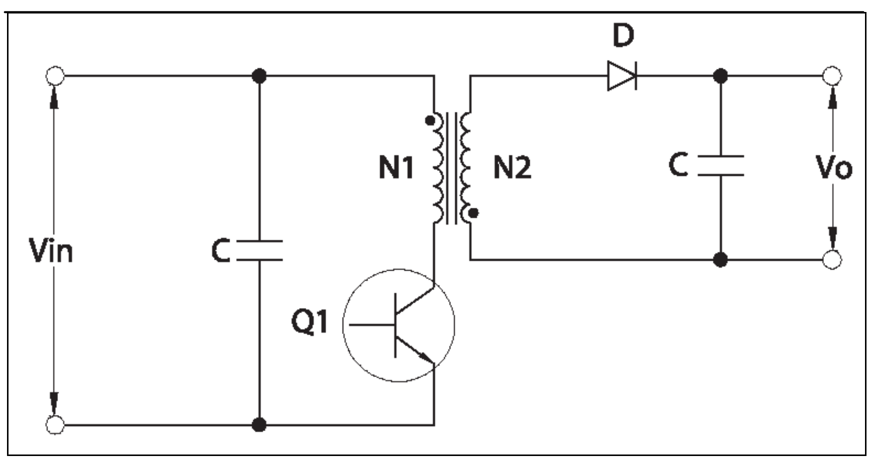

Figure 2.1: A basic flyback topology circuit

The operation of flyback topology normally in both continuous and discontinuous mode depends on the application that is used [3]. The continuous mode even if it has lower peak currents and therefore lower output voltage spike, is seldom used for low-power applications [3]. Table 2.2 shows the description of discontinuous and continuous modes of operation and the Figure 2.2 shows the primary and secondary current in discontinuous and continuous mode.

Table 2.2: Description of discontinuous and continuous modes of operation

Discontinuous Modes of Operation	Continuous Modes of Operation
- All the energy stored in the primary during the power switch ‘on’ time is completely transferred to the secondary and to the load before the next cycle and there is also a dead time between the instant the secondary current reaches zero and the start of the next cycle. - Has higher peak currents and therefore higher output voltage spikes during the turn-off. - Has faster load transient response and lower primary inductance. Therefore the transformer can be made smaller in size. - The reverse recovery time of the output diode is not critical because the forward current is zero before the reverse voltage is applied. - Conducted EMI noise is reduced because the transistor turns on with zero collectors current.	- Still some energy left in the secondary at the beginning of the next cycle. - Has lower peak current and therefore lower output voltage spikes are seldom used for low-power application. Higher voltage and current spikes are not desirable because these exert electrical stress on the output diode and the power switch connected in the primary of the transformer.

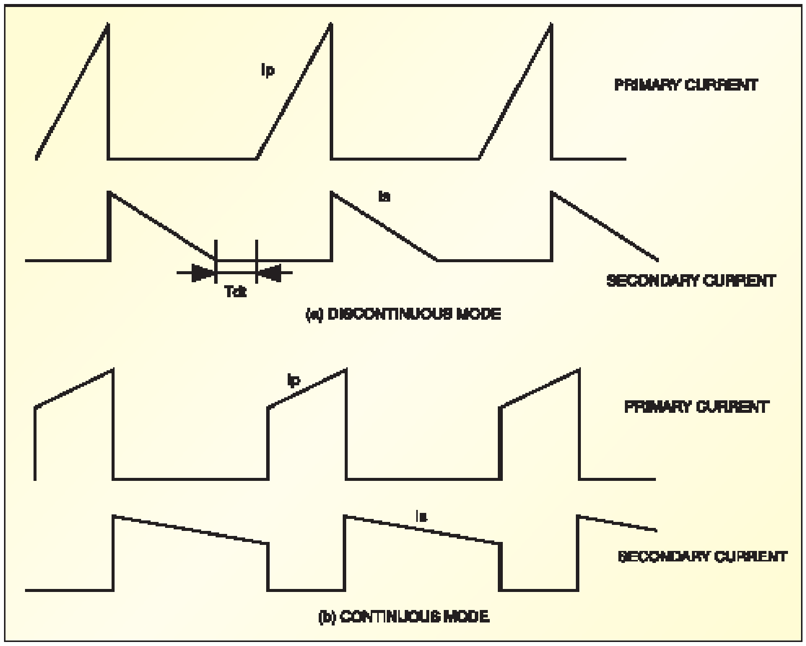

Figure 2.2: Primary and secondary currents in (a)discontinuous and (b)continuous mode

2.2.2 **Flyback Transformer Design**

The flyback transformer (also known as high frequency switching transformer) that is used in flyback topology is used to step-down the high input DC voltage to low output DC voltage. It also is used to isolate the primary and secondary side. This part will explains the steps by steps on how to design the flyback transformer for open-loop system of flyback topology.

Step 1: Define the power supply parameters pertaining to the transformer design

a) Derive output power (P_o)
b) Output voltage (V_o)
c) AC mains frequency (f_L)
d) Input DC voltage ($V_{DC\ input}$)
e) Maximum duty cycle (D_{max}); recommended maximum is 0.5
f) Estimated power supply efficiency (η) at 0.75 to 0.85

Step 2: Primary inductance calculation:

$$I_{AV} = \frac{Po}{\eta \ x \ V_{DC\ input}} \tag{2}$$

$$Ipp = I_{AV} \ x \ \frac{2}{D_{max}}$$

$$= \frac{2Po}{V_{DC\ input} x \ \eta \ x \ D_{max}} \tag{3}$$

$$L_P = \frac{V_{DC\ input} \ x \ D_{max}}{Ipp \ x \ f_s} \tag{4}$$

Where:

I_{AV} = average primary current

L_p = primary inductance

Ipp = peak primary current

f_s = frequency of switching

Step 3: Calculation of the number of turns in primary, secondary and biasing windings

Before the number of primary (Np) is obtained, the number of secondary (Ns) need to be obtained first using formula in equation (5).

$$N_s - T_e + V_o \tag{5}$$

Where T_e is turns per volt. T_e needs to be defined first before using equation (5). If some conditions (explained later) are not satisfied, T_e need to be modified. The numbers of primary turns (Np) is calculated as follows:

$$Np = Ns \ x \ \frac{V_{DC\ input}}{V_o + V_D} \ x \ \frac{D_{max}}{1 - D_{max}} \tag{6}$$

Where V_D is the forward voltage drop of the output diode (D) as shown in Figure 2.1

Step 4: Calculation of the required core size and core air-gap

Each core has different power handling capacity. After selecting the appropriate core, refer to the manufacturer's datasheet to know the required parameters of the core such as inductance factor in nH/turn^2 A_L, effective area A_e and effective length L_e.

$$A_{LG} = \frac{L_p}{{N_p}^2} \ \text{H/Turn}^2 \tag{7}$$

Now calculate the maximum flux density B_{max} using the effective cross – sectional area for the selected core:

$$B_{max} = \frac{N_p x \ I_p x \ A_{LG}}{A_e} \ \text{tesla or webber/m}^2 \tag{8}$$

The calculated B_{max} should be 0.2 to 0.3 tesla if it is not described in core datasheet. If the flux density is obtained more than 0.3 tesla, go back to turn per volt (T_e). Slightly increase T_e to get higher values of Ns and Np and a lower value of A_{LG}. If still B_{max} more than 0.3 tesla, again increase T_e and repeat the process until B_{max} less than 0.3 tesla. Now calculate the required air gap. Before determine the air gap, the relative permeability of the ungapped core (μ_s) is need to be calculated first. This is calculated from core parameters A_e (effective cross-sectional area in cm^2), L_e (effective magnetic path length in cm^2) and A_L (inductance factor in nH/turn^2) as follows:

$$\mu_s = \frac{A_L x \ L_e}{0.4\pi \ x \ A_e} \tag{9}$$

The gap length (L_g) can now be calculated. The gap should be ground only in the centre leg of the core. If the gap is put into the outer legs, it will need to be half that calculated here. The minimum limit for L_g is 0.051mm and L_g is calculated from the following equation:

$$L_g = \left(\frac{0.4\pi \, x \, {N_p}^2 x \, A_e}{L_p} - \frac{L_e}{\mu_s}\right) \text{x } 10^{-3} \text{ mm} \qquad (10)$$

Step 5: Selection of wire area primary and secondary windings

For primary and secondary, choose a wire that doesn't generate too much heat in the winding at the desired current. For that, use the current density (J, in amp/mm^2) to calculate the area of the conductor. The accepted value of J is 3A/mm^2 to 6A/mm^2.
A good value of J is 4.5A/mm^2 as this gives a smaller wire size without undesirable temperature rise in the winding and the core.

The area of primary winding conductor (Ap):

$$Ap = \frac{Input\ rms\ current\ (Irms)}{J} \text{ mm}^2 \qquad (11)$$

Similarly, the area of secondary winding conductor (As):

$$As = \frac{Output\ current\ (Io)}{J} \text{ mm}^2 \qquad (12)$$

After calculating area of the primary and the secondary (in mm^2), select the wire gauge from appendix 1.

2.3 **Pulse-Width Modulation (PWM)**

PWM is a powerful technique for controlling analog circuits with a processor's digital outputs. PWM is employed in a wide variety of applications ranging from measurement and communications to power control and conversion. PWM uses a square wave whose duty cycle is modulated resulting in the variation of the average value of the waveform. PWM can be used to reduce the total amount of power delivered to a load without losses normally incurred when a power source is limited by resistive means. This is because the average power delivered is proportional to the modulation duty cycle. With a sufficiently high modulation rate, passive electronic filters can be used to smooth the pulse train and recover an average analog waveform. High frequency PWM power control systems are easily realizable with semiconductor switch. The discrete on/off states of the modulation are used to control the state of the switch which correspondingly controls the voltage across or current through the load. The major advantage of this system is the switch are either off and not conducting any current, or on and have (ideally) no voltage drop across them. The product of the current and the voltage at any given time defines the power dissipated by the switch, thus (ideally) no power is dissipated by the switch. Realistically, semiconductor switches such as MOSFETs or BJTs are non-ideal switches, but high efficiency controllers can still be built. Figure 2.3 shows the example of PWM duty cycle signal.

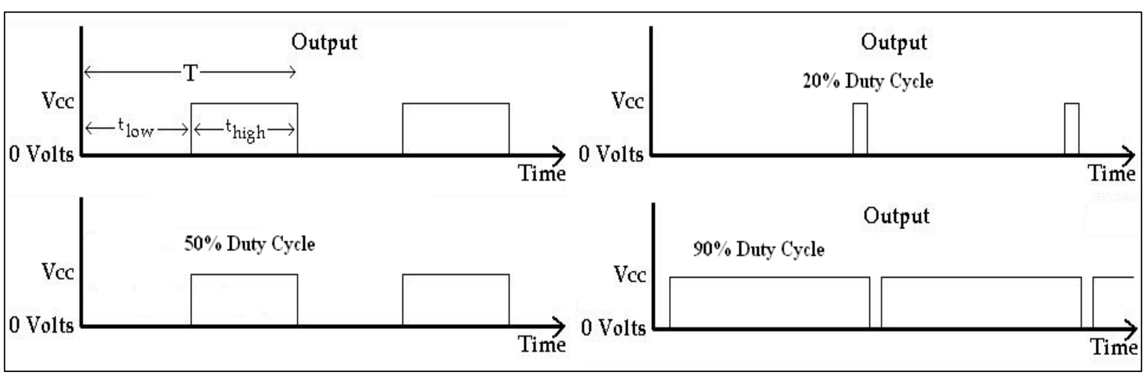

Figure 2.3: Example of PWM duty cycle signal

2.4 PIC 16F877A MICROCONTROLLER

Many microcontrollers include on-chip PWM units. PIC 16F877A has two, each of which has a selectable on-time and period. The duty cycle is the ratio of the on-time to the period; the modulating frequency is the inverse of the period. To start PWM operation, the data sheet suggests the software should:

- Set the period in the on-chip timer/ counter that provides the modulating square wave.
- Set the on-time in the PWM control register.
- Set the direction of the PWM output, which is one of the general-purpose I/O pins.
- Start the timer.
- Enable the PWM controller.

2.5 MOSFET Driver

To turn a power MOSFET on, the gate terminal must be set to a voltage at least 10 volts greater than the source terminal (about 4 volts for logic level MOSFETs). This is comfortably above the $V_{gs(th)}$ parameter. One feature of power MOSFET is that they have a large stray capacitance between the gate and the other terminals, C_{iss}. The effect of this is that when the pulse to the gate terminal arrives, it must first charge the capacitance up before the gate voltage can reach the 10 volts required. The gate terminal then effectively does take current. Therefore the circuit that drives the gate terminal should be capable of supplying a reasonable current so the stray capacitance can be charged up as quickly as possible. The best way to do this is to use a dedicated MOSFET driver chip.

2.5.1 **Bootstrap Component Selection for Control IR2110**

2.5.1.1 **Operation of the Bootstrap Circuit**

In the Figure 2.4, the V_{bs} voltage (the voltage difference between the V_b and V_s pins on the control IC) provides the supply to the high side driver circuitry of the control IC's. This supply needs to be in the range of 10-20V to ensure that the Control IC can fully enhance the MOS Gated Transistor (MGT) being driven, some of International Rectifier's Control IC's include undervoltage detection circuits for V_{bs}, to ensure that the IC does not drive the MGT if the V_{bs} voltage drops below a certain voltage (V_{bsuv} in the datasheet). This prevents the MGT from operating in a high dissipation mode.

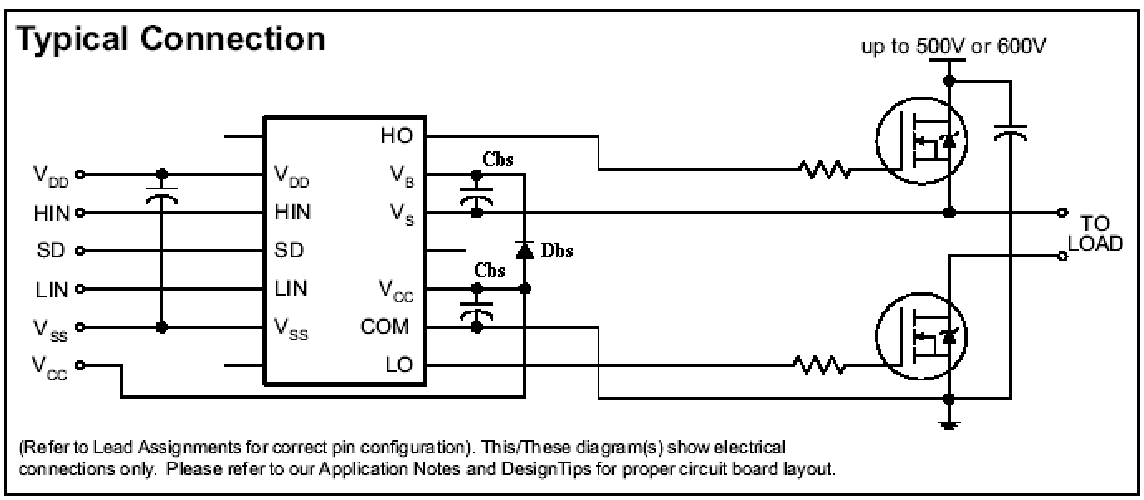

Figure 2.4: Bootstrap diode/capacitor circuit used with IR control IC's

This V_{bs} supply voltage is a floating supply that sits on top of the V_s voltage (which in most cases will be a high frequency square wave). There are a number of ways in which the V_{bs} floating supply can be generated, one of these being the bootstrap method described here in this design tip. This method has the advantage of being simple and inexpensive but has some limitations, duty cycle and on-time are limited by the requirement to refresh the charge in the bootstrap capacitor. The bootstrap supply is formed by a diode and capacitor combination as shown in Figure 2.4. The operation of the circuit is as follows. When V_s is pulled down to ground (either through the low side FET or the load, depending on the circuit configuration), the bootstrap capacitor (C_{bs}) charges through the bootstrap diode (D_{bs}) from the 15V Vcc supply. Thus providing a supply to V_{bs}.

2.5.1.2 **Factor Affecting the Bootstrap Supply**

There are five influencing factors which contribute to the supply requirement from the V_{bs} capacitor. These are:

1. Gate Charge required to enhance MGT
2. I_{qbs} - quiescent current for the high side driver circuitry
3. Currents within the level shifter of the control IC
4. MGT gate-source forward leakage current
5. Bootstrap capacitor leakage current

Factor 5 is only relevant if the bootstrap capacitor is an electrolytic capacitor, and can be ignored if other types of capacitor are used. Therefore it is always better to use a non-electrolytic capacitor if possible.

2.5.1.3 **Calculation of the Bootstrap Capacitor Value**

The following equation details the minimum charge which needs to be supplied by the bootstrap capacitor:

$$Q_{bs} = 2Q_g + \frac{I_{qbs}\,(\max)}{f} + Q_{ls} + \frac{I_{cbs}(leak)}{f} \qquad (13)$$

Where:

Q_{bs} = Minimum charge needs to be supplied by the bootstrap capacitor
Q_g = Gate charge of high side FET
$I_{cbs(leak)}$ = Bootstrap capacitor leakage current
I_{qbs} =Quiescent current for the high side driver circuitry
Q_{ls} = Level shift charge required per cycle = 5nC (500/600V IC's) or 20nC (1200V IC's)

The bootstrap capacitor must be able to supply this charge, and retain its full voltage, otherwise there will be a significant amount of ripple on the V_{bs} voltage, which could fall below the V_{bsuv} undervoltage lockout, and cause the H_O output to stop functioning. Therefore the charge in the C_{bs} capacitor must be a minimum of twice the above value. The minimum capacitor value can be calculated from the equation (14).

$$C_{bs} \geq \frac{2Q_{bs}}{V_{cc}-V_f-V_{ls}-V_{min}} \tag{14}$$

Where:

C_{bs} = Bootstrap capacitor value
Q_{bs} = Minimum charge needs to be supplied by the bootstrap capacitor
V_{cc} = Low side fix supply voltage
V_f = Forward voltage drop across the bootstrap diode
V_{LS} = Voltage drop across the low side FET (or load for a high side driver)
V_{min} = Minimum voltage between V_B and V_S

The C_{bs} Capacitor value obtained from the equation (14) is the absolute minimum required, however due to the nature of the bootstrap circuit operation, a low value capacitor can lead to overcharging, which could in turn damage the IC. Therefore to minimize the risk of overcharging and further reduce ripple on the V_{bs} voltage, the C_{bs} value obtained from the equation (14) should be multiplied by a factor of 15 (rule of thumb). The C_{bs} capacitor only charges when the high side device is off, and the V_s

voltage is pulled down to ground. Therefore the on time of the low side switch (or the off time of the high side switch for a high side driver) must be sufficient to ensure that the charge drawn from the C_{bs} capacitor by the high side driver can be fully replenished. Hence there is inherently a minimum on time of the low side switch (or off time of the high side switch in a high side driver). Also in a high side switch configuration where the load is part of the charge path, the impedance of the load can have a significant effect on the charging of the C_{bs} bootstrap capacitor. If the impedance is too high the capacitor will not be able to charge properly, and a charge pump circuit may be required.

2.5.1.2 **Selection of the Bootstrap Diode**

The bootstrap diode (D_{bs}) needs to be able to block the full power rail voltage, which is seen when the high side device is switched on. It must be a fast recovery device to minimize the amount of charge fed back from the bootstrap capacitor into the V_{cc} supply and similarly the high temperature reverse leakage current would be important if the capacitor has to store charge for long periods of time. The current rating of the diode is the product of the charge calculated from equation (13) and the switching frequency. Therefore:

Diode Characteristics

V_{RMM} = Power rail voltage
max trr = 100ns
I Forward = Q_{bs} x f

Where:

Q_{bs} = Minimum charge needs to be supplied by the bootstrap capacitor
f = Switching frequency

CHAPTER III

METHODOLOGY AND DESIGN

3.1 Background

This chapter explains about how to design the adjustable SMPS. This chapter also will cover about designing the flyback transformer, PIC programming, part by part circuits and the complete circuit.

Before looking the detail of designing the adjustable SMPS, it is best to begin with brief review of the system design. Figure 3.1 shows the complete system design of SMPS.

3.2 System Design

The adjustable SMPS was designed to supply DC voltage to the load below 100 Watts and the output voltage of this SMPS can be adjusted to 5, 9 and 12 volt. To design this adjustable SMPS, it consists of three parts where the first part is flyback circuit, second part is microcontroller circuit and third part is MOSFET driver. The Figure 3.1 shows the overall of the adjustable SMPS system design.

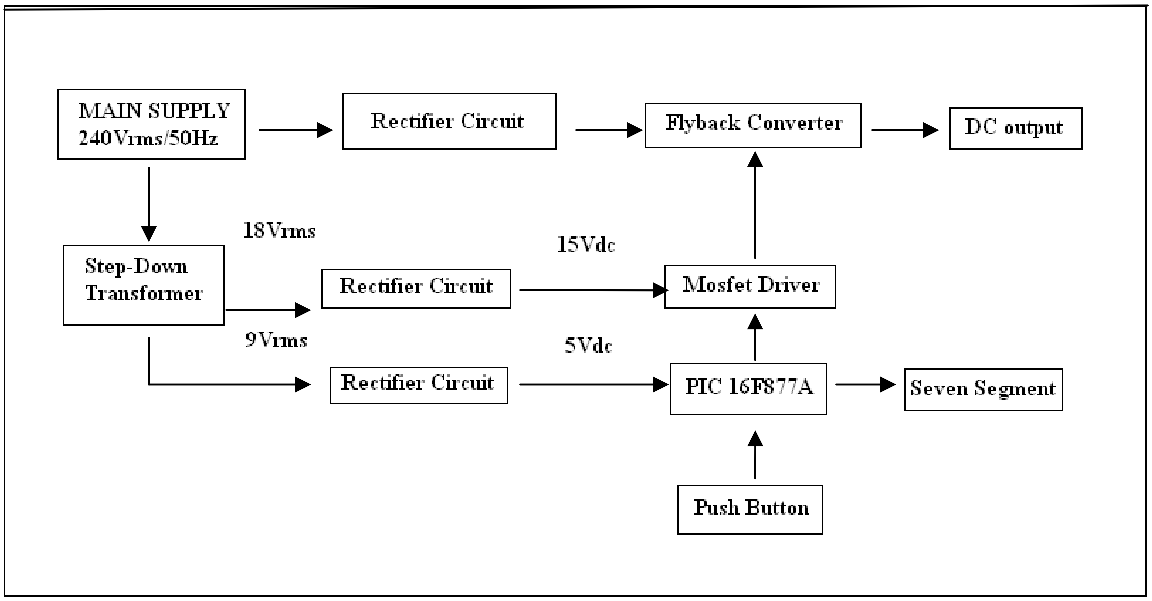

Figure 3.1: System design of adjustable power supply

For the first part, 240Vrms from main supply is rectified to high DC voltage first. Then it will be connected to flyback circuit where the flyback circuit is used to step-down the high DC voltage from rectifier circuit to low DC voltage. The PWM technique is applied to MOSFET at flyback circuit where this MOSFET will act as switch. The MOSFET (2SK2607) will be used because it can sustain high input voltage and current about 800Volt and 9A. The rise time (t_r) and fall time (t_f) also small about 25ns. The rapid on and off the MOSFET and changing the duty cycle will regulate the DC output voltage.

The second part is a microcontroller circuit. The PIC 16F877A microcontroller will be used in this adjustable SMPS project. This PIC is chosen because it has 33 pins input/output (I/O) and PWM modules where these 33 pins of I/O is enough for the PIC 16F877A interfaces with three push buttons and two seven segments like Figure 3.16. The PWM modules in the PIC will be used to generate PWM. The seven segments will be used to display output DC voltage value that are 5, 9 and 12 Volt. The push buttons are used as input and will give signal to PIC to generate PWM. Through programming, each of the push buttons is programmed where when each of push button is pressed, the PIC will generate different duty cycles. From the flyback formula, the increase of duty cycle will increase the regulate output voltage.

The third part is a MOSFET driver circuits. This MOSFET driver is needed in this adjustable SMPS project because to turn fully on the MOSFET (2SK2607), minimum 10 volt is needed to be supplied to MOSFET gate. However, the maximum output voltage that PIC can supply is 5 volt only. So using this MOSFET driver, the turn on output voltage of the PWM that is generated by PIC can be increased from 5 volt to above 10 volt. Thus the MOSFET can be turned fully on and fully off and switching losses can be reduced.

3.3 Flyback Connection Circuit

This part will describe and show the connection of rectifier and flyback topology circuit. This part also will show the step by step on how to design the high frequency switching transformer.

3.3.1 **Rectifier Circuit**

The rectifier converter is an AC to DC converter. In this adjustable SMPS, it is used to convert the 240Vrms to about 340Vdc (ideally). The Figure 3.2 shows the connection of SMPS rectifier circuit. This rectifier circuit is used to rectify the AC voltage, 240Vrms to DC voltage, 340Vdc. The R2, R3, R4 and R5 are thermistors where they are used to reduce the surge current at the first cycle that drawn by capacitor (C1). These thermistors vary with temperature where before current flows to them, the thermistor resistance value is high. As the current flows in the thermistor, the temperature of the themistor will increase and the resistance values will decrease. Finally the resistance values in thermistor become very low and too small losses will occur at thermistors thus the SMPS is still efficient. The capacitor (C1) is used to reduce the output voltage ripple. The bigger capacitance values of capacitor (C1), the smaller the output voltage ripple. However, it not suitable to use largest capacitance value of capacitor (C1) because it will draw much current at the first cycle of AC voltage and will damage the diode (D1).

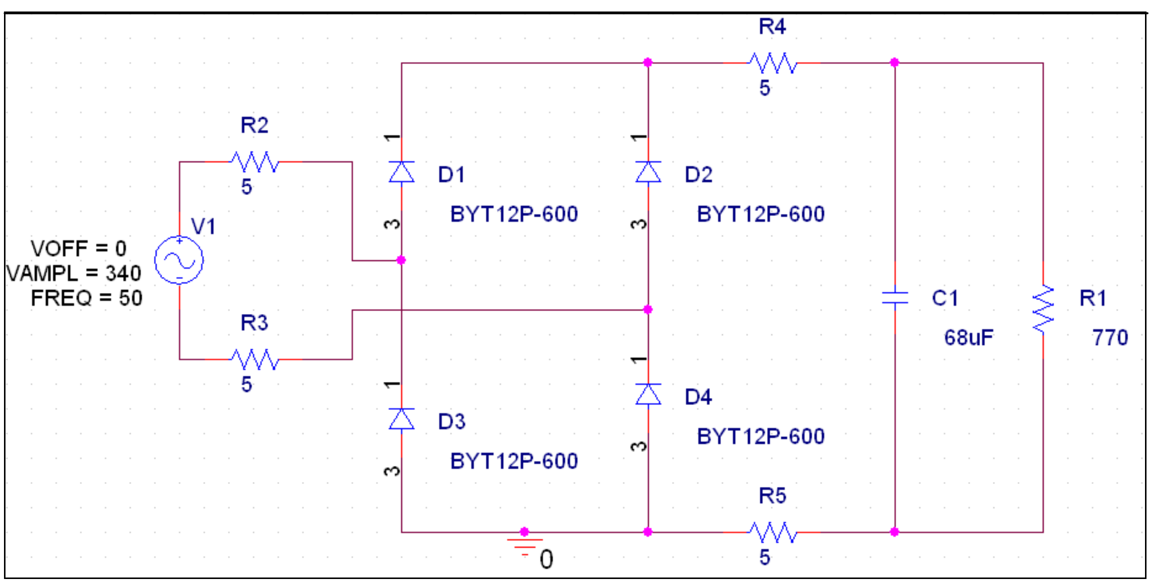

Figure 3.2: Rectifier circuit

Figure 3.3 shows the output ripple voltage is 2.77 Volt and Figure 3.4 shows the output ripple current is 1.8mA. The outputs ripples voltage and current are quite small and the curves are close to straight line. However, the disadvantage of using 4.43mF of capacitor C1 is it will cause high surge current at diode (D1) like Figure 3.5 and absolutely will damage this diode and maybe other components also.

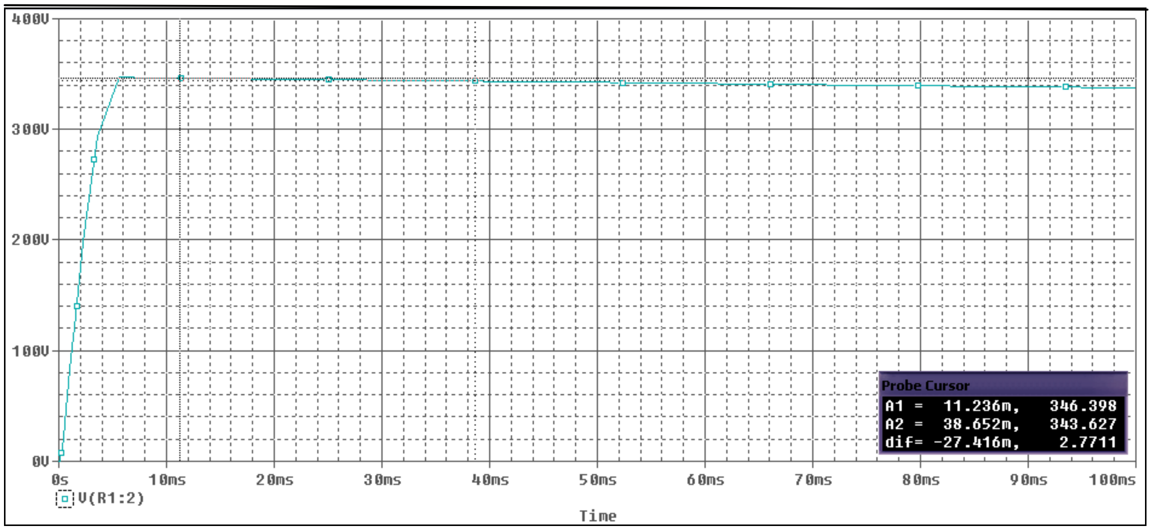

Figure 3.3: Output voltage using 4.43mF of capacitor C1

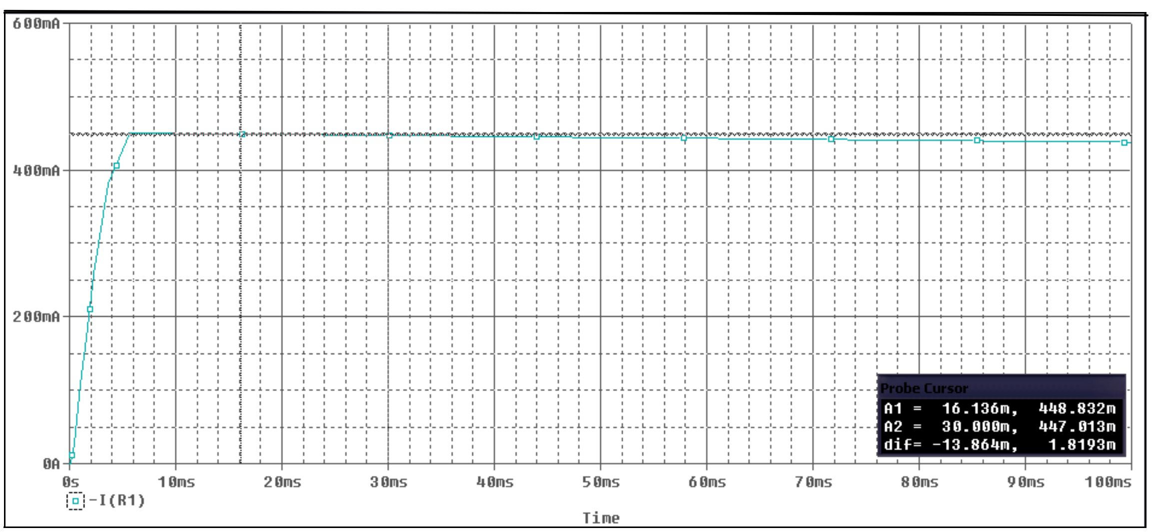

Figure 3.4: Output current using 4.43mF of capacitor C1

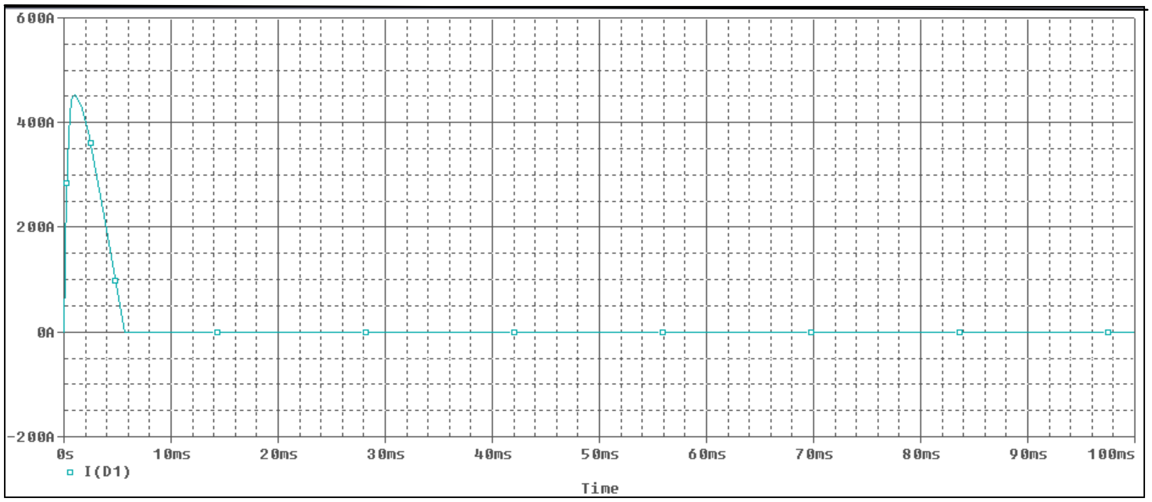

Figure 3.5: Current drawn by the 4.43mF of capacitor C1

The Figure 3.6 and 3.7 show the output voltage and current using 68uF of capacitor (C1). The output voltage in Figure 3.6 shows that the output ripple voltage is 40.87 volt and in Figure 3.7 shows that the output ripple current is 51.47 mA. The ripples for both current and voltage are quiet large but the surge current at diode D1 is low. Refer to Figure 3.8, the surge current at diode D1 is 7A only. Compare of using 4.43mF of capacitor (C1), 68uF of capacitor (C1) is suitable to use as ripple filter in rectifier circuit. Figure 3.9 shows the input voltage and current at diode (D1).

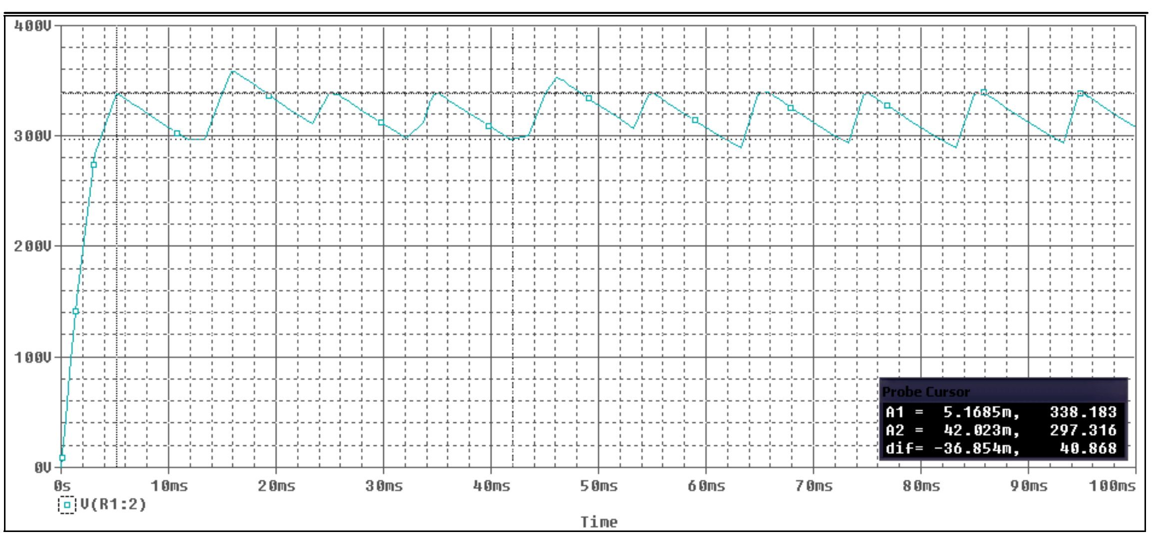

Figure 3.6: Output voltage using 68uF of capacitor C1